OPERATING AND MAINTENANCE MANUAL

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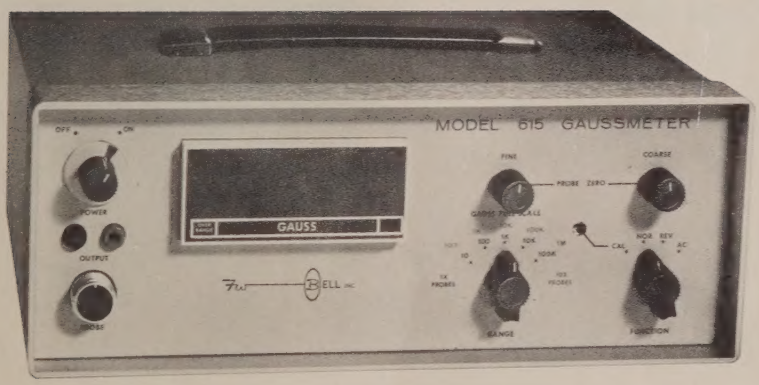
MODEL 615 GAUSSMETER

F.W. BELL

Subsidiary, Magnetics & Electronics, Inc.

F.W. Bell Gaussmeter Model 615
Instruction Manual

MODEL 615
GAUSSMETER
Operating and Maintenance Manual



F.W. BELL
Subsidiary, Magnetics & Electronics, Inc.

F. W. BELL, INC.
6120 Hanging Moss Road
Orlando, Florida 32807
Phone: 305-678-6900
TWX: 810-853-3115

UN-01-112
MAY 1982

SIMPLIFIED OPERATING INSTRUCTIONS

1. Connect the 615 Gaussmeter to the appropriate power source. Connect the probe to the 615. Turn the instrument on and allow 30 minutes for warm-up.

2. To calibrate the 615 Gaussmeter using its internal calibration feature, set the FUNCTION switch to CAL. The RANGE switch may be in any position. Adjust the CAL screwdriver adjustment to obtain a full-scale (1.000) meter-reading or a 100mV dc reading on any external readout instrument connected to the output jacks.

3. The probe is zeroed using the COARSE and FINE adjustments on the instrument. Set both controls to about mid-setting. Rotate the RANGE switch counter clockwise until a reading is obtained on the meter. Adjust the COARSE control to bring the reading near zero while reducing the RANGE setting. On the 10 gauss range the FINE control may be used for better resolution of the zero adjustment. See Section IV-2b for details on the effects of the Earth's magnetic field and other residual fields on the zero adjustment.

4. The 615 is now ready to measure magnetic fields. For complete details on any of the above procedures consult the appropriate section of the manual which follows.

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SECTION I
General Description

I-1 GENERAL

The Model 615 Gaussmeter is a precision magnetic flux measuring instrument, featuring high stability, solid state construction. It has been designed especially for use with the recently developed Hall effect magnetic field probes manufactured by F. W. Bell, Inc.

A wide range of standard transverse and axial, as well as special probes, is available. All probes are directly interchangeable using a simplified self-calibration technique. Factory calibration of probes is carried out with reference to a laboratory standard magnet. This standard is measured by the Nuclear Magnetic Resonance (NMR) technique and provides traceability to the National Bureau of Standards. The user can then set this calibration into the instrument by the use of the simplified high accuracy built-in CAL procedure.

Measurement range extends from 100 mG (milligauss) per scale division (10 G full scale) to 1 MG (megagauss) full scale. Both dc and ac fields can be measured directly using the digital panel meter. DC polarity is preserved for direction information when tracing and plotting fields. AC fields of up to 400 Hz are read out as an rms value for sine wave fields.

Output jacks are provided on the front panel. Output voltage is 100 millivolts full scale and is proportional to the field for dc and ac fields up to 2k Hz.

Simplicity of operation, wide measurement range and high accuracy make the Model 615 a versatile instrument for measurement in the laboratory or in the field, as well as for production testing and process control.

SECTION II
Specifications

II-1 ELECTRICAL AND PERFORMANCE SPECIFICATIONS

(a) Measurement Ranges:
Measurement of static (dc) or varying (ac to 2k Hz) magnetic field strength in the range of 10 gauss full scale to 1,000,000 gauss full scale in decade steps as follows:

1X probes	10, 100, 1 kG, 10 kG, 100 kG
10X probes	100, 1 kG, 10 kG, 100 kG, 1 MG

(b) Calibration:
1. Internal calibrating procedure is referenced to a standard NMR magnet traceable to the National Bureau of Standards.
2. Internal calibration error does not exceed ±0.5%.

(c) Available Standard Probes:
One hundred and ten different Hall effect field probes are available to meet the challenging requirements of virtually any application. Please see the F. W. Bell Gaussmeter Probes literature sheet for probe models and prices. Consult the factory for special probe requirements.

(d) Accuracy:
1. Accuracy is the sum of the accuracies of the instrument, the probe, and the calibration source. The instrument accuracy is ±0.5% of full scale, and the internal calibration accuracy is ±0.5% of reading. For example, assume a 615 Gaussmeter used with a model STB1-0402 probe calibrated with the internal calibration output. The total accuracy is ±0.5% of full scale (instrument), plus ±0.5% of reading, (internal calibration), plus ±1% of reading (probe) for a total accuracy of ±0.5% of full scale plus ±1.5% of reading.
2. For Sinusoidal ac Fields (In AC Function):
0 to 60 Hz; ±5% of full scale
60 to 400 Hz; down 3% max. from 60 Hz response
3. Meter accuracy:
±0.1% of reading ±1 digit.
4. Improved accuracy obtainable by using probe deviation curves* and, at specific test points, by reference to a known calibration field.
* Available on special order.

(e) Stability
1. Line voltage:
Error negligible for ±10% line voltage changes
2. Temperature effects excluding probe influences:
Approx. ±3% of reading total over the range of −10°C to +60°C (can be removed by using internal calibration feature)
3. Probe temperature effects:
See the F.W. Bell Gausmeter Probe literature sheet for the specifications for the probe being used.
4. Probe temperature effects Zero Field influence:
See the F.W. Bell Gausmeter Probe literature sheet for the specifications for the probe being used.

(f) Output Jacks:

1. Output voltage:	100 millivolts dc FS
2. Source impedance:	10 kΩ approx.
3. ac field frequency response:	See response curve Fig. IV-3
4. Response time for full scale step input:	4 msec approx.
5. RMS Noise:	approx. 40 dB below full scale

(g) Power Requirements:
1. Line input:

Volts	105-125 V	or	210-250 V
Frequency	50-60 Hz		50-60 Hz
Current	.063 A		.032 A
Power	7.2 W		7.2 W

(h) Warm Up Time:
The digital panel meter needs ½ hour of warm up time to insure stable meter readings.

II-2 PHYSICAL SPECIFICATIONS, CONTROLS AND CONNECTORS

(a) Front Panel:
1. Power Switch:
This rotary switch turns on the primary power to the instrument.
2. Range Switch:
The full scale range is set by this switch in decade steps marked in the 1, 10 sequence. It covers the range from 1 gauss to 1M gauss, the full range of the instrument. Red scale for 10X type probes.
3. Function Switch:
This switch selects the mode of operation. It includes the measurement positions for dc fields of both normal and reverse polarities, and for ac fields, and the calibration position for internal CAL.
4. Probe Zero Controls:
COARSE and FINE zeroing controls are provided to balance each individual probe for zero output in the absence of a magnetic field. They will also suppress small residual dc fields up to approximately 30 gauss.
5. CAL Control:
The screwdriver CAL control is used to calibrate the instrument using the internal calibration feature as well as calibration to a standard magnet. Calibration through external indicating instruments is also possible with connection to the output jacks.
6. Output Jacks:
The black and red front panel jacks will accept a standard double banana plug with ¾'' spacing. They provide an output voltage proportional to the full-scale field, for use with external instrumentation. The polarity is positive for upscale meter readings and negative for downscale indications. The black jack is grounded to the chassis.

(b) Rear Panel:
1. Power Cord Receptacle:
The 3 pin power cord receptacle accepts the detachable power cord. The power cord is equipped with three conductors and is terminated in a three-prong plug recommended by The National Electrical Manufacturers' Association. The round pin is connected to the case and grounds the instrument case and output terminals when used with the appropriate receptacle. An adapter may be used for connection to a standard two-contact receptacle. The ground is brought out of the adapter by means of a short wire which should be connected to a suitable ground for protection of operating personnel. Only when a ground is supplied by associated equipment should this ground be unused to prevent common ground currents. The Model 615 is normally wired for 117V nominal 50-60 Hz. To change it to 234V, the primaries of the power transformer must be changed from parallel to series connection.
2. BCD Output:
A rear panel connector provides a positive true, TTL compatible, BCD output with logic state $1 \geq +2.0V$ into a 1KΩ load and logic state $0 \leq +0.5V$.

(c) Internal Fuse:
The fuse holder accepts a standard 3 AG size fuse. The fuse should be rated at 1/8 A Slow Blow. It is not necessary to replace the fuse when converting to 234 V operation.

(d) Overall Dimensions:
5¾'' high 14'' wide 8½'' deep

(e) Weight:
Shipping 14 lbs. Net 8 lbs. Add 3½ lbs. for optional battery.

SECTION III
Installation and Pre-Operation Adjustments

III-1 POWER

(a) Power Requirements:
The Model 615 can be operated from standard ac line voltage (117 V or 234 V, 50-60 Hz, 7.2 watts).

(b) Operation:
Before turning the instrument on, make certain the power to be used matches the voltage and frequency ratings of the gaussmeter.
Connect a probe to the input socket. It is important that the plug is pushed firmly into the panel socket observing the key slot, then the clamp ring screwed on until it is snug. With power off, check the meter mechanical zero by aligning the pointer with its image in the mirror. If necessary, adjust the screw on the meter face to bring the pointer to exactly zero reading. Set the panel controls as follows:

RANGE switch to 100 K
FUNCTION switch to NOR

Turn the power switch on and allow 30 minutes warm up before making any measurements or calibrating.

III-2 PROBE ZEROING ADJUSTMENTS

To reduce the residual probe output to zero, the probe zero controls are used. Set both controls to about mid setting. Rotate the RANGE switch counter clockwise until a reading is obtained on the meter. Adjust the COARSE control to bring the reading near zero while reducing the RANGE setting. On the 10 gauss range, the FINE control may also be used for better resolution of zero adjustment.

Because the earth's magnetic field is well within the measurement capabilities of the gaussmeter, the effects of this and residual fields from other sources on zeroing must be considered, especially when measurements are made on the higher sensitivity ranges (100 gauss and below). Check Section IV-2b for details on types of zeroing.

III-3 CALIBRATION PROCEDURE

(a) General:
The calibration procedure should be carried out before using the instrument for magnetic field measurements. It should also be made whenever probes are changed. Allow sufficient time for warm up stability before calibrating.
Calibration consists of adjusting the amplifier gain in accordance with the sensitivity of the probe and the element control current by using one of the following two methods.

(b) Calibration Against Internal CAL Signal:
Calibration against the internal CAL signal is a simple, easy to apply technique which will, in most cases, produce the best possible accuracy. Calibration against a reference magnet can produce better accuracy only if the reference magnet is better than ±0.5% and the probe linearity curve is available (supplied on special order). The accuracy and stability of the internal calibration signal is dependent only on precision, high stability resistors and the initial factory calibration. Therefore, long-term, high stability is a characteristic of this technique. It is recommended that, unless a very high accuracy reference magnet and probe linearity data are available, the internal calibration be used.
After the instrument and probe have warmed up (30 min.) set the FUNCTION switch to CAL. The RANGE switch may be in any position. Adjust the CAL screwdriver adjustment to obtain a full-scale (1.0) meter reading (or a 100 millivolt dc reading on any external readout instrument connected to the output jacks). The gaussmeter and probe are then calibrated to the accuracy shown in the specifications under Section II-1d. This adjustment must be repeated if the probe is changed. The calibration may be conveniently rechecked at any time by setting the FUNCTION switch to CAL.

(c) Calibration Against a Reference Magnet:
Greater accuracy can be achieved by the use of a reference magnet, provided the magnet has an accuracy of better than ±0.5% and the probe linearity data are known. Deviation error curves can be obtained at a nominal charge for any probe, at the time of purchase, or by returning the probe to F. W. Bell, Inc.
The linearity curve is machine drawn using a precision electromagnet and is an error plot for the particular probe measured. It is a plot of the probe's deviation from the true value over the measurement range.
The curve is plotted with actual flux density along the horizontal X-axis and the deviation from true value, in gauss, vertically along the Y-axis. Thus, the locus of deviation errors of, for example, 1% of the actual field, will appear on the sheet as a diagonal line passing through the 1% of value points.
To calibrate using the linearity curve and reference magnet, the following procedure should be used. It is important that the absolute zero procedure be carried out prior to calibration by this method (see Section IV-2b). The Hall probe must be carefully positioned in the field to the correct location and orientation to respond to the correct field magnitude (maximum reading) without alignment errors. Set the RANGE switch to the proper range giving the maximum on-scale meter reading (or external readout instrument reading.) Add the reference magnet specified field, in gauss, to the deviation, in gauss, read from the linearity curve at that flux density. Adjust the CAL control to obtain a reading equal to the sum. For example if the reference magnet were specified at 9.8 kG and the deviation from the curve was −10 G, then the adjustment would be made to obtain 9.79 kG on the meter (or external readout instrument if used).

(d) AC Field Calibration:
No separate ac field calibration is necessary. If the gaussmeter has been properly calibrated for dc fields, then the signal at the output jacks for ac fields will be calibrated with the exception of the effects of the frequency response. Figure IV-3 shows the effect of frequency response on output jack voltage and panel meter reading.

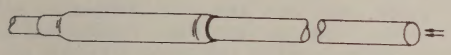
SECTION IV
Operating Instructions

IV-1 THE PROBE

(a) General:
The standard probes are divided into two basic categories depending on field direction response: transverse and axial. Figure IV-1 shows the shape and size of various probes. In addition, special probes can be designed to meet unusual requirements. Contact F. W. Bell, Inc. for information and quotations.

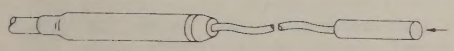
Note that probes are supplied for various flux measurement ranges. For accurate readings, make sure that the probe is being used within its specified range of measurement. When probes are used for measurement higher then their specified range, increased deviation from linear response will result. Such measurements would not be accurate as absolute readings, but might be useful where only a relative indication is sufficient.

AXIAL PROBE:



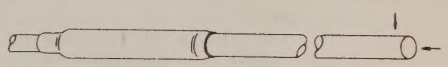
TRANSVERSE PROBE:

AXIAL FLEXIBLE:

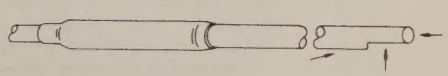


TRANSVERSE FLEXIBLE:

TWO-AXIS PROBE:



THREE-AXIS PROBE:



REQUIREMENTS	SUGGESTED PROBE CONFIGURATION
general use; durable	HEAVY DUTY
measure flux density in awkward places	FLEXIBLE
measure flux density in a small gap	STANDARD DUTY (laboratory use)
measure homogeneous fields* from 0.001 G to 5 G; high sensitivity	MAGNAPROBE
high linearity; low temperature coefficient; accurate field measurement to 150 kG	10X PROBE**
multi-axis field measurement	2-AXIS PROBE; 3-AXIS PROBE
withstand low temperature (down to –270°C)	CRYOGENIC
monitor instantaneous difference between two field points; field mapping, homogeneity testing	DIFFERENTIAL

*averages flux density along 9" probe length
** 10X probe sensitivity is one-tenth standard probe (1X) sensitivity

(b) Probe Handling Precautions:
Reasonable care should be exercised in handling the probe. Avoid excessive shock, pressure, bending or otherwise straining the element mount. The element can be fractured if the mounting is over-stressed since it is brittle as well as rigid. Since the active area is a good heat conductor, it should be protected and prevented from touching very hot or cold objects.
The Hall probes will withstand normal handling without damage, however, it is not indestructible. The following instructions should be followed to insure against breakage.

1. Always select the most durable probe that can be used for the application, to increase the probe service life.

2. Avoid sharp bends in probes in flexible mountings.

3. Do not allow compression or impact forces to strike the Hall element. Rigid mountings are brittle and can be fractured by excessive pressure, shock, or impact forces. A fractured Hall element cannot be repaired—it must be replaced.

4. Do not expose the probe or element to temperatures in excess of the −20°C to +60°C range, unless the probe or Hall element was designed for other temperatures.

(c) Transverse Probes:
A transverse probe, as its name implies, has its flux response direction transverse to the probe handle axis. The element is encapsulated on the end of a flexible strip to lessen the chance of breakage due to stressing by the handle.

In figure IV-1, notice that the flux vector is shown entering the Hall element at right angles (90°) to the plane of the element surface. This is the direction of maximum Hall output. Magnetic fields entering the element at some other angle to the surface cause an output response proportional to the 90° component. That is, the response will be B cos Θ where B is the field magnitude and Θ is the angle of the field to the perpendicular.

(d) Axial Probes:
The axial probe has its flux response direction along the axis of the probe handle. The element is encapsulated on the end of the probe extension tube. If the field is directed at some angle with respect to the probe axis, only the axial component will produce an output, just as only the transverse component will produce output for transverse probes.

IV-2 MEASUREMENT PROCEDURE

(a) General:
After completing the pre-operational adjustments described in Section III, the unit is ready for operation. Allow sufficient time after turn-on for the unit and probe to reach operating temperature (5 min.). It is advisable to position the probe securely in the measurement position using a probe holding fixture or clamp whenever possible. It may be difficult or impossible to obtain a good field measurement unless the probe is stable. The probe may be hand-held only when operating on the higher ranges (100 gauss and above) and the field is fairly uniform over a reasonable area.

Errors in readings due to temperature changes at the probe can be corrected by using the mean probe temperature coefficient and computing corrections (see Section IV-2e).

(b) Zeroing:
Since Hall probes do not have exactly zero output in a zero field, it is necessary to electrically zero the gaussmeter before taking any readings. Two types of zeroing are possible: Absolute and Relative.

Absolute zero is required whenever it is desired to know the actual field at the probe. As its name implies, the controls are adjusted to give zero reading at zero field. Because of the ever-present earth's field and possible stray fields from other sources, it is necessary to shield the probe to achieve zero field during the time of adjustment. The zero gauss chamber accessory available from F. W. Bell, Inc., is a dual mu-metal can assembly which effectively shunts all external stray fields around the internal volume. By slipping this chamber over the probe end, a zero field condition is created at the element and the gaussmeter is adjusted for zero output by the procedure of Section III-2. Use care not to place the zero gauss chamber in a strong magnetic field. Also, it must not be allowed to come into direct contact with a magnet, since it may become slightly magnetized and will not provide a true zero. It can be demagnetized by slowly passing the chamber through the ac field of a demagnetizer coil carrying ac line current.

The zero chamber provides a "true" zero reference. Readings taken in the presence of the earth's ambient field will generally have the earth's field, or some component of it, included in the reading of the unknown field. Thus, it may be necessary to subtract the ambient field reading from the total to obtain the value of the unknown field. To avoid this subtraction, the method of relative zeroing may be used. In this case the gaussmeter is zeroed after the probe has been placed in the measurement position, without using the zero gauss chamber. The ambient field is therefore zeroed out electrically in the gaussmeter. This method is successful only if the field to be measured can then be presented to the probe without changing the probe position with relation to the ambient field, and without altering the ambient field at the probe during measurement. The change in field at the probe will be measured by the gaussmeter as an absolute value, and the ambient field excluded from the reading. Since the probe position must remain fixed during the measurement, this method is not always practical. The zero controls are capable of suppressing residual fields of up to about 30 gauss.

Since the ambient field seldom exceeds 1 gauss, the precautions mentioned above apply only when measuring fields less than 500 or 1000 gauss. If a magnet has an iron structure which will modify the ambient field by its presence, it may be necessary to take several measurements in different orientations with respect to the earth's field. Obtain the two extreme values and use the mean value between these as the correct value. The zero adjustments should be checked frequently, if possible, during the course of a measurement, particularly when using low ranges. If a change in temperature occurs at the probe, rezeroing may be necessary. Zero drift versus temperature is small and is not compensated. The zero controls are never used to shift the calibration of the gaussmeter.

(c) Calibration Check:
A calibration check can easily be made at any time during a series of measurements without disturbing the probe by using the internal calibration procedure. Refer to Section III-3b on calibration.

(d) Operation:
1. DC Fields:
For dc field measurements set the FUNCTION switch to NOR and the RANGE switch to a range higher than the expected field. The meter will read up scale if the field direction aligns with the probe sensitivity direction as shown in Figure IV-1. If the meter tends to read below zero, the field direction is reversed and the probe can be turned over or the FUNCTION switch can be set to REV. Switch the RANGE switch to a range which gives the greatest on-scale meter reading. To read the magnitude of the field, adjust the probe for maximum reading. If a desired direction component of a field is to be measured, set the probe so that the sensitive direction aligns with the desired component. The meter will then read the component.
The measured value is determined from the meter reading and RANGE switch setting. The RANGE switch indicates the full scale value in gauss of the meter reading. For example, if the RANGE switch is set on 10 kG and the meter reads 1.0 on the 0 to 1 scale, then the field is 10 kG. If the meter reading were 0.5, then the field would be 5,000 gauss.
2. AC Fields:
For ac field measurement, the dc field should first be zeroed out to prevent gaussmeter overload and erroneous readings. Two methods of ac measurement are possible with the Model 615.
(a) If a direct reading on the panel meter is desired, the FUNCTION switch must be placed in the AC position. The RANGE switch should be switched to the range giving the highest on-scale meter reading. Probe should be aligned for maximum reading or desired direction component as described in the section on measuring dc field. The meter will indicate ac fields from approximately 10 Hz to 2k Hz. A dc voltage proportional to meter reading (100 mV full scale) will appear at the output jacks and may be used with external dc readout equipment. An ac component will also appear at the output jacks. This ac signal will not generally be useful since its amplitude will be subject to the effects of the output filter and the waveform will appear in full-wave rectified form rather than the waveform of the actual flux field. The gaussmeter panel meter and output jack dc voltage are calibrated to read the rms value for a sine wave flux. For non-sinusoidal waveforms, the average value can be obtained by multiplying the meter reading by 0.9. See Figure IV-3 for frequency response.
(b) If it is desired to use external ac readout equipment, the FUNCTION switch may be placed in the NOR position. In this operating mode, the voltage at the output jacks will follow the instantaneous polarity and amplitude of the ac field. The gaussmeter panel meter will not provide useful readings. The ac waveform at the output jacks will represent the flux waveform within the limitations of the output frequency response (see Figure IV-3 for output filter frequency response curve). At higher frequencies where the output is attenuated, do not attempt to switch to a lower range to increase output as this will cause gaussmeter overload and erroneous readings. The correct range is that which gives the highest on-scale reading on the gaussmeter panel meter when the FUNCTION switch is momentarily turned to the AC position, and then returned to the NOR position.
3. Overloading:
Because the amplifying system used in this gaussmeter will amplify ac and dc fields simultaneously, attempting to measure a small ac field in the presence of a large dc field or a small dc field in the presence of a large ac field can overload the amplifier and cause erroneous measurements. When measuring dc fields, especially on the sensitive ranges, check for ac fields by connecting an oscilloscope or ac voltmeter to the output jacks. If an ac reading exceeding 30 mV is encountered, the dc measurement may be in error. Switch to the next less sensitive range. If the dc reading has not changed, the ac component of field has not overloaded the amplifier. If at any time there is a discrepancy between ranges of more than 2% of full scale on the meter, there is the possibility that the amplifier is being overloaded, and the above tests should be made. Also when making ac measurements, the component of any dc fields must be kept below 10% of the range in use. This can usually be accomplished by using the zero controls to suppress the small earth's field or residual fields. Relative zeroing as described in Section IV-2b will remove any dc fields up to about 30 gauss. If this is not sufficient to prevent overloading, then a less sensitive than normal range must be used to prevent the undesired dc field from overloading the amplifier. In the AC FUNCTION, any dc field not properly zeroed out will cause an erroneously high output indication.

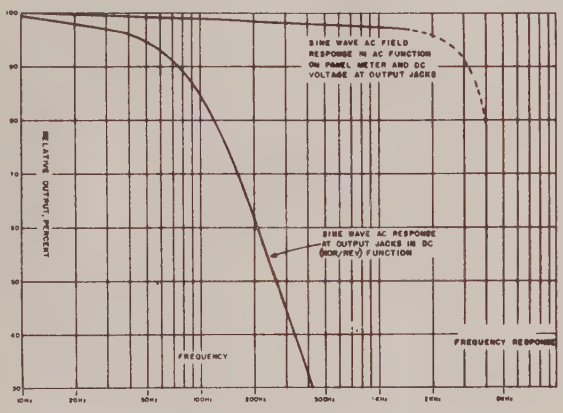

SINE WAVE AC FIELD RESPONSE IN AC FUNCTION ON PANEL METER AND DC VOLTAGE AT OUTPUT JACKS
SINE WAVE AC RESPONSE AT OUTPUT JACKS IN DC (NOR/REV) FUNCTION
RELATIVE OUTPUT, PERCENT
FREQUENCY
FREQUENCY RESPONSE

FIGURE IV-3

(e) Temperature Effects:
All Hall probes exhibit a certain temperature coefficient. This value can be found in the specifications for the type of probe being used. If the probe temperature is known relative to the temperature at which it is calibrated, correction for the temperature effects can be applied to the measurement readings.
To correct for temperature influence, the following formula can be used:

$$B_a = B_g \left(1 - (t_{pm} - t_{pc}) \frac{t_c}{100}\right)$$

where: B_a = the actual value of the field being measured (unknown).
B_g = the value of the field as indicated by the gaussmeter.
t_{pm} = temperature of probe at time of field measurement in degrees C.
t_{pc} = temperature of probe at time of calibration in degrees C. (25° C when using internal CAL method).
t_c = temperature coefficient of probe in % per degree C. (Typical value is -0.025% per deg. C).

This formula will correct the gaussmeter reading (B_g) to give the actual field (B_a) for measurements under different temperature conditions. Notice that t_c is a negative number, and the minus sign must be carried into the formula.

IV-3 OUTPUT JACKS

The output jacks provide the electrical output of the instrument. They provide the highest resolution, stability and accuracy capability of the Model 615. The red and black jacks are at the standard ¾'' spacing to accept a dual banana plug. The red jack is the output which is positive for upscale meter readings and negative for below zero meter indications. The black jack is the common and is grounded to the gaussmeter case. The voltage available is 100 mV for full scale meter reading and directly proportional to the field at the probe. The source resistance is 10kΩ. See frequency response Figure IV-3.

IV-4 PROBE DEVIATION CURVES

Machine drawn error curves can be obtained at a nominal charge for any probe, at the time of purchase or by returning the probe to F. W. Bell, Inc. The use of the probe deviation curves for calibrating is described in Section III-3c.

To use the curves to correct the field measurements, locate the field value, as indicated on the gaussmeter, on the horizontal axis of the curve. Use the right half of the curve for positive or normal direction fields and the left half for negative or reverse direction fields. Read the deviation in gauss from the curve. If the deviation is positive (above the axis), the probe output is high and the error is to be subtracted from the indicated value. Negative probe deviations are added to the readings to obtain the corrected value.

IV-5 TOTAL FLUX DETERMINATION

The Hall-effect sensing device is inherently responsive to magnetic flux density and not to total flux lines. It is not dependent on rate-of-change of flux as is a search coil.

From the basic definitions:

$$\text{GAUSS} = \text{WEBERS PER SQUARE METER} \times 10^4$$
$$\text{GAUSS} = \text{LINES PER SQUARE INCH} \times .1550$$

The Hall probe is equally useful in homogenous, uniform low-gradient fields and in high-gradient fields, although the low-gradient fields are capable of more accurate measurement. If the flux density is uniform and unidirectional over a given area, the total flux through the area is found by multiplying by the area in question.

$$\text{(Flux) WEBERS} = \text{GAUSS} \times \text{SQ. METERS} \times 10^{-4}$$
$$= \text{GAUSS} \times \text{SQ. CM} \times 10^{-8}$$

$$\text{(Flux) LINES} = \frac{\text{GAUSS} \times \text{SQ. INCHES}}{.1550}$$

When the Hall generator is moved in a plane, the component of flux normal to this plane will be indicated. If the field varies in magnitude over the area, it is necessary to integrate the values of flux density over the area in question. The flux density value indicated by the Hall probe output is the effective value over the active area of the Hall generator. Fortunately, the Hall-Pak devices have extremely small active area. The standard transverse probe active area is only about 0.003 square inch, and sensitivity is essentially uniform over this area.

Absolute measurements of total flux of magnets having odd shape or high length-to-diameter ratio are best made using the search coil and standard fluxmeter methods. In many cases, however, valuable data are obtained by air-gap flux density measurements when the magnet is mounted in its working structure. Also, accurate comparison data can be obtained on almost all magnets of various sizes and shapes using a Hall probe to measure pole face density in comparison to a magnet selected as a standard of reference.

SECTION V
Theory of Operation

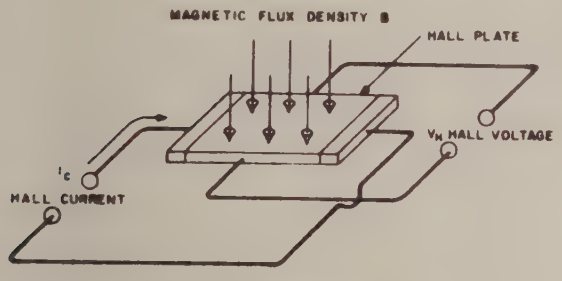
V-1 GENERAL

The basic principle of magnetic flux measurement used in the Model 615 Gaussmeter may be described as a flux-modulated carrier-amplifier system. A locally generated ac carrier signal is fed as an exciting current to the Hall element. The flux to be measured at the probe modulates the ac carrier within the Hall sensor, producing an ac output voltage which is accurately proportional to flux density. The flux modulated ac carrier output is amplified by the carrier amplifier and then restored to a flux proportional voltage by the synchronous demodulator without loss of polarity (field direction) information. The demodulator drives the panel meter and output jacks.

If the field is time varying, the demodulated output will be instantaneously proportional to the flux waveform up to 400 Hz. In the AC function, the demodulator is made self-synchronous to provide a dc output which drives the panel meter and output jacks.

V-2 THE SENSING ELEMENT

The Hall-Pak generator used for magnetic flux sensing is a semiconductor device operating on the Hall-Effect principle. It consists of a thin rectangular wafer of high-purity indium arsenide with 4 leads attached, Fig. V-1.



THE HALL GENERATOR

FIGURE V-1

The application of control current I_c to the Hall generator results in a flow of charge carriers through the semiconductor material in the direction of its long dimension. When the Hall generator is placed in a magnetic field, the Lorenx force, acting on the moving charges, deflects them at right angles to the direction of their motion through the Hall plate. This is the same force that deflects the electron beam in a cathode ray tube.

The resulting build-up of charge carriers along the sides of the wafer produces the Hall voltage, and this voltage appears as an output at connections made on each side of the element. Hall voltage V_H is directly proportional to the flux density B and to the magnitude of control current I_c .

$$V_H = K_H(\bar{B} \times \bar{I}_c)$$

The three factors V_H , I_c and B and mutually perpendicular. If the magnetic flux vector B is not perpendicular to the face of the Hall generator, the Hall output will be proportional to the component of B that is perpendicular to the element. The constant of proportionality K_H is called the Hall sensitivity constant, and is approximately 0.075 volt per kG-ampere for 1X probes, and 0.0075 volt per kG-ampere for 10X probes.

V-3 CIRCUIT OPERATION

(a) Introduction:

This section describes the overall gaussmeter circuit operation. Check the block diagram and the complete schematic for circuitry details. Although the circuit design is relatively straightforward, it is recommended that an understanding of the circuit operation be acquired before attempting to service or adjust the instrument.

(b) General Operation Description:

The Hall generator is supplied with an exciting current, I_c , from the 5 kHz oscillator and current regulated amplifier. The Hall output voltage, V_H (the flux modulated carrier signal), is connected to the gaussmeter input summing circuit. At this point, the zeroing voltage from the zero controls is subtracted from the Hall generator output. The difference is amplified depending on the range in use to produce the proper output. The amplifier output feeds the synchronous demodulator which converts the amplified flux modulated carrier into a flux proportional output voltage. This output voltage then feeds the output jacks and meter for dc fields. AC fields may be measured by connecting external ac readout equipment to the output jacks. Direct readout of ac fields on the gaussmeter panel meter may be obtained by switching to the AC FUNCTION switch position. In this position, a dc voltage will appear at the output jacks which is proportional to the ac field being measured.

(c) Detailed Operating Description:

1. General:

The circuit is made up of six basic functional sections: the probe, the input section, the amplifier section, the detector and meter, the current regulated I_c supply, and the power supply. The block diagram shows essential operating functions; however, various circuit details have been eliminated or altered for clarity. Check the complete schematic for all circuit details.

(d) Detector Zero Adjustment:
Place the probe in the zero gauss chamber and zero the gaussmeter down to the 10 gauss range. Switch to the 100 K range and adjust R143 to obtain zero dc voltage on the meter.

(e) Quadrature Adjustments:
An excessive residual reading with the FUNCTION switch in AC could indicate a large quadrature signal. To check, set the RANGE switch to 10 G and FUNCTION switch to REV. Place probe in zero gauss chamber and carefully adjust the COARSE and FINE zero controls to obtain zero meter reading on the panel meter. Connect the oscilloscope between the output of the second amplifier and chassis. The amplifier output is the coaxial wire with the yellow color tape on the circuit board. Residual signal should be below 15 mV with the CAL control set to max clockwise. If it is higher than this, it means that:
1. The probe quadrature adjustment (in probe connector) has been disturbed, or
2. The probe cables have been overstressed or cable wires shifted at probe or connector end due to loosening of the strain relief.
3. The probe input socket J1 wiring adjustment has been altered or has loosened due to hard usage.

The quadrature (90° phase-shifted) signals generated in the gaussmeter input are the result of mutual inductive coupling between the probe control current pair and the Hall output pair. These pairs are tightly twisted except at interconnecting tie points and where wires are positioned and cemented to minimize quadrature. These lead placement adjustments are made at the input socket J1 rear and inside the probe connector. Before attempting quadrature adjustment, make certain that the signal cannot be further reduced with the zero controls. Socket J1 adjustment should be changed only if a probe is used that is known to be good and correctly adjusted. Perhaps the most likely point to change would be in the probe due to handling. If several probes are used, all should be checked to insure interchangeability. Extremely small changes in the position of one of the current leads with respect to one of the Hall leads will make a noticeable change in quadrature output. Loosen the cable plug housing and carefully unscrew the housing. The approximately 1" long piece of solid wire (with tubing) may be shifted from its central position to adjust quadrature, then resealed with cement.

VI-6 TROUBLE SHOOTING

The following suggestions and procedures are recommended when difficulty is encountered in operating the instrument:

(a) The probe should be checked whenever erratic operation is obtained, particularly at low levels. A fractured probe element will produce unstable and erratic operation, and the zero adjustment on low ranges will become particularly unstable. Check the cable also for poor contact or wire breakage. Light finger pressure against the probe element should produce only small temporary effect.
(b) Make the preliminary performance tests, most of which can be made without auxiliary test equipment. The source of trouble should be localized, in general, with these tests.
(c) Refer to the circuit diagrams and to the parts lists, by using schematic reference symbols, to obtain detailed information on parts used.
(d) It is important to replace parts with the same type and electrical value as originally used. Parts having F. W. Bell, Inc. part numbers are parts designed especially for the Model 615 and should be obtained directly from the factory.
(e) Use care in replacing diodes and transistors; do not apply excessive heat to the leads. A heat sink is recommended, such as gripping with pliers on the lead between the body of the component and the soldering iron.
(f) If necessary to return this instrument to the factory for repair, refer to WARRANTY section.

VT-7 PARTS LIST

ABREVIATIONS

Cer	Ceramic
CF	Carbon Film
EM	Electrolytic miniature type
F	Farad
FOP	Fact. adj. for opt. perf.
HM	Hot molded
K	Kilo or 10^3
M	Meg or 10^4
MF	Metal Film
μ	Micro or 10^{-6}
MME	Molded miniature epoxy
Ω	ohm
p	Pico or 10^{-12}
V	Working volts
Var	Variable
W	Watt
WW	Wire wound

NOTE: Components with schematic reference numbers below 100 are located in the chassis wiring; numbers above 100 are located on the circuit boards.

615 PARTS LIST

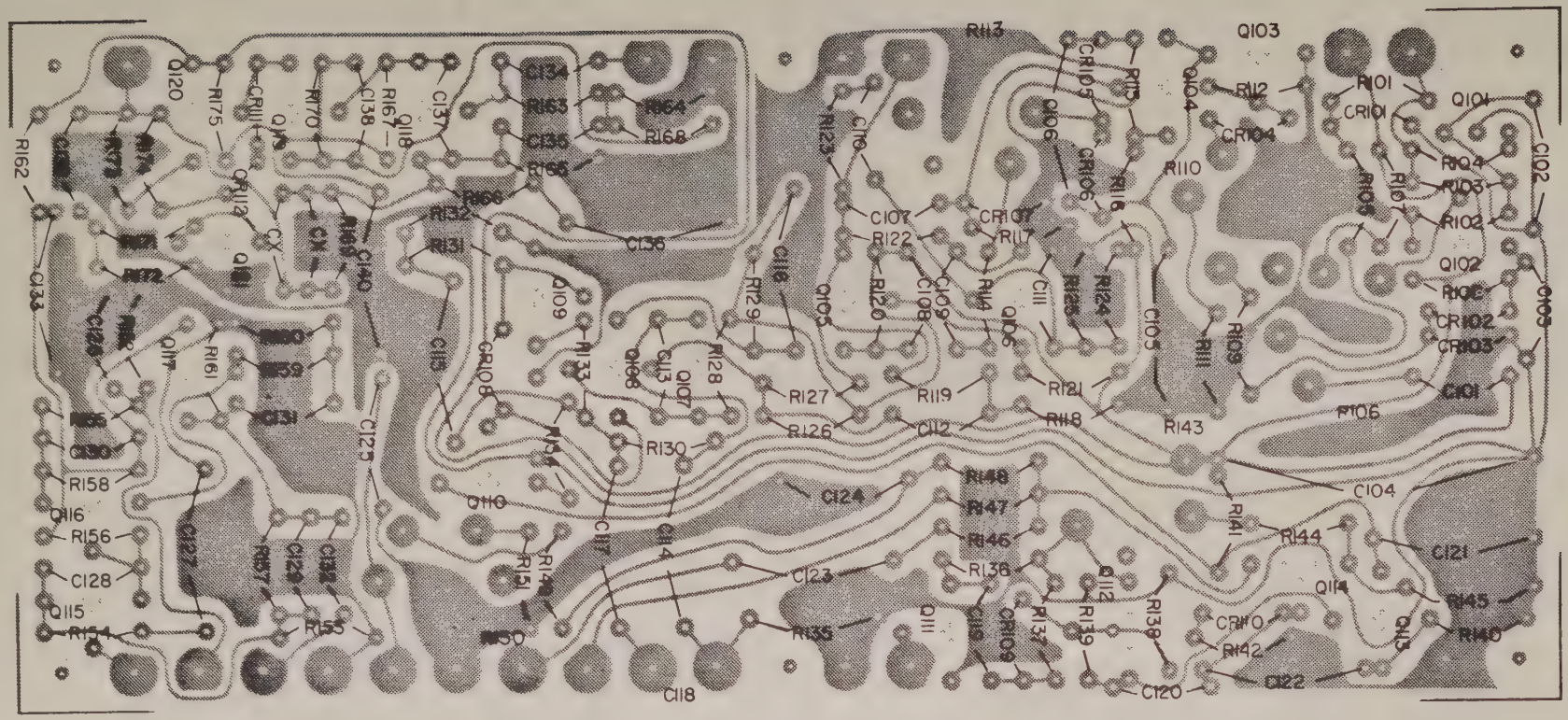
ABBREVIATIONS

Schematic Ref.	Value	Spec.	Type	Bell Part No.
R1	10Ω ¼W	5%	CF Fixed	11475
R2	5kΩ		HM Var	21170
R3	270kΩ ¼W	5%	CF Fixed	11591
R4	5.6kΩ ¼W	5%	CF Fixed	11551
R5	250Ω		HM Var	21180
R6	5.1Ω 2W	5%	WW Fixed	19880
R7	5.1Ω 2W	5%	WW Fixed	19880
R8	105Ω ¼W	1%	MF Fixed	15792
R9	5.6kΩ ¼W	5%	CF Fixed	11551
R10	26.7kΩ ¼W	1%	MF Fixed	16520
R11	2Ω 1/10W	1/10%	WW Fixed	18360
R12	2Ω 1/10W	1/10%	WW Fixed	18360
R13	45kΩ 1/8W	¼%	MF Fixed	14730
R14	4.5kΩ 1/8W	¼%	MF Fixed	14710
R15	450Ω 1/8W	¼%	MF Fixed	14680
R16	50Ω 1/8W	¼%	MF Fixed	14650
R20	9.09kΩ 1/8W	¼2	MF Fixed	14700
R22	909Ω 1/8W	¼%	MF Fixed	14670
R23	101Ω 1/8W	¼%	MF Fixed	14660
R24	20kΩ		Var	21190
R25	1MΩ ¼W	5%	CF Fixed	11605
RX	FOP ¼W	5%	CF Fixed	
R101	47kΩ ¼W	5%	Fixed	11573
R102	1kΩ ¼W	5%	CF Fixed	11553
R103	1kΩ ¼W	5%	Cf Fixed	11553
R127	62kΩ ¼W	5%	CF Fixed	11576
R128	2.4kΩ ¼W	5%	CF Fixed	11542
R129	120Ω ¼W	5%	CF Fixed	11511
R130	5.1kΩ ¼W	5%	CF Fixed	11550
R131	510Ω ¼W	5%	CF Fixed	11526
R132	510Ω ¼W	5%	CF Fixed	11526
R133	2.7Ω ¼W	5%	CF Fixed	11461
R134	2.7Ω ¼W	5%	CF Fixed	11461
R135	4.7Ω 2W	5%	WW Fixed	19860
R136	820Ω ¼W	5%	CF Fixed	11531
R137	1.8kΩ ¼W	5%	CF Fixed	11539
R138	62kΩ ¼W	5%	CF Fixed	11576
R139	3.9kΩ ¼W	5%	CF Fixed	11547
R140	470Ω ¼W	5%	CF Fixed	11525
R141	10Ω ¼W	5%	CF Fixed	11475
R142	470Ω ¼W	5%	CF Fixed	11525
R143	1kΩ		WW Var	22140
R144	470Ω ¼W	5%	CF Fixed	11525
R145	1Ω 2W	5%	WW Fixed	19800
R146	453Ω ¼W	1%	MF Fixed	15910
R147	536Ω ¼W	1%	MF Fixed	15940
R148	15kΩ ¼W	5%	CF Fixed	11561
R149	15kΩ ¼W	5%	CF Fixed	11561
R150	5kΩ		WW Var	22170
R151	13kΩ ¼W	5%	CF Fixed	11560
R104	2.7Ω ¼W	5%	CF Fixed	11461
R105	8.2kΩ ¼W	5%	CF Fixed	11555
R106	2kΩ		WW Var	22150
R107	3kΩ ¼W	5%	CF Fixed	11544
R108	180Ω ¼W	5%	CF Fixed	11515
R109	2kΩ ¼W	5%	CF Fixed	11540
R110	2kΩ		WW Var	22150
R111	2.4kΩ ¼ W	5%	CF Fixed	11542
R112	62kΩ ¼W	5%	CF Fixed	11576
R113	1kΩ	10%	Cer Var	22044
R114	1.6kΩ ¼W	5%	CF Fixed	11538
R115	22Ω ¼W	5%	CF Fixed	11483
R116	3.9kΩ ¼W	5%	CF Fixed	11547
R117	150kΩ ¼W	5%	CF Fixed	11585
R118	301Ω ¼W	1%	MF Fixed	15880
R119	1.3kΩ ¼W	1%	MF Fixed	16090
R120	240Ω ¼W	5%	CF Fixed	11518
R121	8.2kΩ ¼W	5%	CF Fixed	11555
R122	5.1kΩ ¼W	5%	CF Fixed	11550
R123	10kΩ ¼W	5%	CF Fixed	11557
R124	16kΩ ¼W	5%	CF Fixed	11562
R125	27kΩ ¼W	5%	CF Fixed	11567
R126	22kΩ ¼W	5%	CF Fixed	11565
R175	120Ω ¼W	5%	CF Fixed	11511
R176	62Ω ¼W	5%	CF Fixed	11504
R177	6.8Ω ¼W	5%	CF Fixed	11553
R178	75kΩ ¼W	5%	CF Fixed	11578
R179	6.8kΩ ¼W	5%	CF Fixed	11553
R180	75kΩ ¼W	5%	CF Fixed	11578
R181	6.8kΩ ¼W	5%	CF Fixed	11553
R182	75kΩ ¼W	5%	CF Fixed	11578
C1	1200μF	15V	EM	23240
C2	82 pF 1000 V	10%	Cer	25360
C101	10μF	6 V	EM	22930
C102	0.015μF 200 V	10%	MME	24500
C103	10μF	6 V	EM	22930
C104	1000μF	10 V	EM	23050
C105	100μF	12 V	EM	23160
C106	100μF	12 V	EM	23160
C107	10μF	6 V	EM	22930
C108	10μF	6 V	EM	22930
C109	10μF	6 V	EM	22930
C110	0.0033μF	200 V	10% MME	24430
C111	0.0033μF	200 V	10% MME	24430
C112	10μF	6 V	EM	22930
C113	0.015μF	200 V	10% MME	24500
C114	100μF	12 V	EM	23160
C115	100μF	12 V	EM	23160
R152	47kΩ ¼W	5%	CF Fixed	11573
R153	12kΩ ¼W	5%	CF Fixed	11559

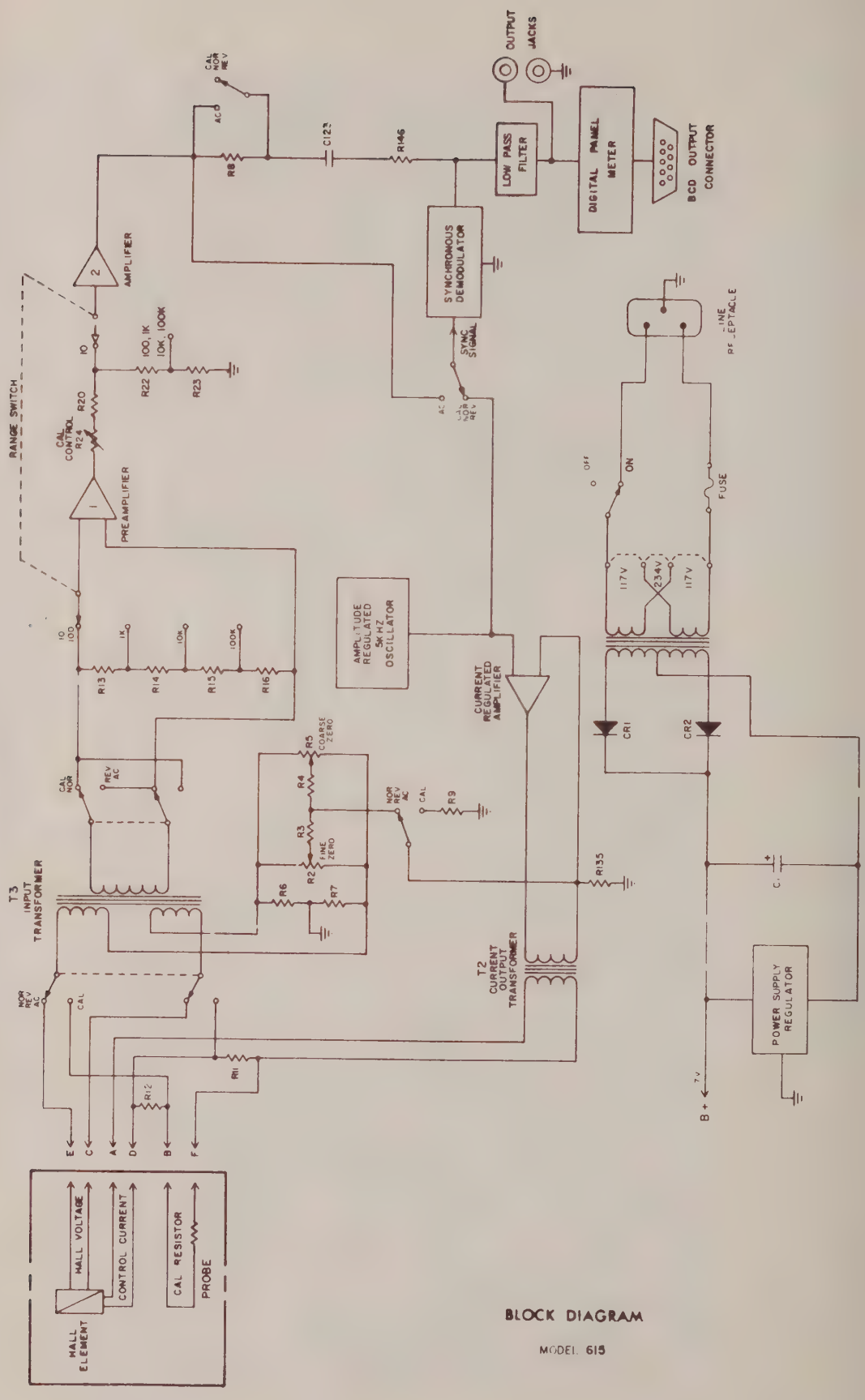
Schematic Ref.	Value	Spec.	Type	Bell Part No.
R154	301Ω ¼W	1%	MF Fixed	15880
R155	62kΩ ¼W	5%	CF Fixed	11576
R156	13kΩ ¼W	5%	CF Fixed	11560
R157	20kΩ ¼W	1%	MF Fixed	16490
R158	2kΩ ¼W	5%	CF Fixed	11540
R159	5.1kΩ ¼W	5%	CF Fixed	11550
R160	5.6kΩ ¼W	5%	CF Fixed	11551
R161	1kΩ ¼W	5%	CF Fixed	11533
R162	330Ω ¼W	5%	CF Fixed	11521
R163	127Ω ¼W	1%	MF Fixed	16650
R164	47kΩ ¼W	5%	CF Fixed	11573
R165	16kΩ ¼W	5%	CF Fixed	11562
R166	174Ω ¼W	1%	MF Fixed	15820
R167	12kΩ ¼W	5%	CF Fixed	11559
R168	62kΩ ¼W	5%	CF Fixed	11576
R169	54.9kΩ ¼W	1%	MF Fixed	16590
R170	1.8kΩ ¼W	5%	CF Fixed	11539
R171	5.1kΩ ¼W	5%	CF Fixed	11550
R172	5.1kΩ ¼W	5%	CF Fixed	11550
R173	22Ω ¼W	5%	CF Fixed	11483
R174	22Ω ¼W	5%	CF Fixed	11483
T1	LB1931 Power Transf.			26310
F1	Fuse 1/8 A, SB		307	30680
T2	Output Tansformer			26330
T3	Input Transformer			26320
M1	Meter Digital			10672/10675
S1	Power Switch			34290
S2	Range Switch Ass. Sub-A			1110
S3	Function Swit. Ass. Sub-A			1163
Q101	2N3403	Transistor		28910
Q102	2N508A	Transistor		28920
Q103	2N508A	Transistor		28920
Q104	2N4401	Transistor		29130
Q105	2N508A	Transistor		28920
Q106	2N3710	Transistor		29000
Q107	2N3710	Transistor		29000
Q108	2N508A	Transistor		28920
Q109	2N2706	Transistor		28930
Q110	2N2430	Transistor		28910
Q111	2N508A	Transistor		28920
Q112	2N1305	Transistor		28780
Q113	PN4917	Transistor		29150
Q114	2N1305	Transistor		28780
Q115	2N3707	Transistor		28990
Q116	PN4917	Transistor		29150
Q117	2N4401	Transistor		29130

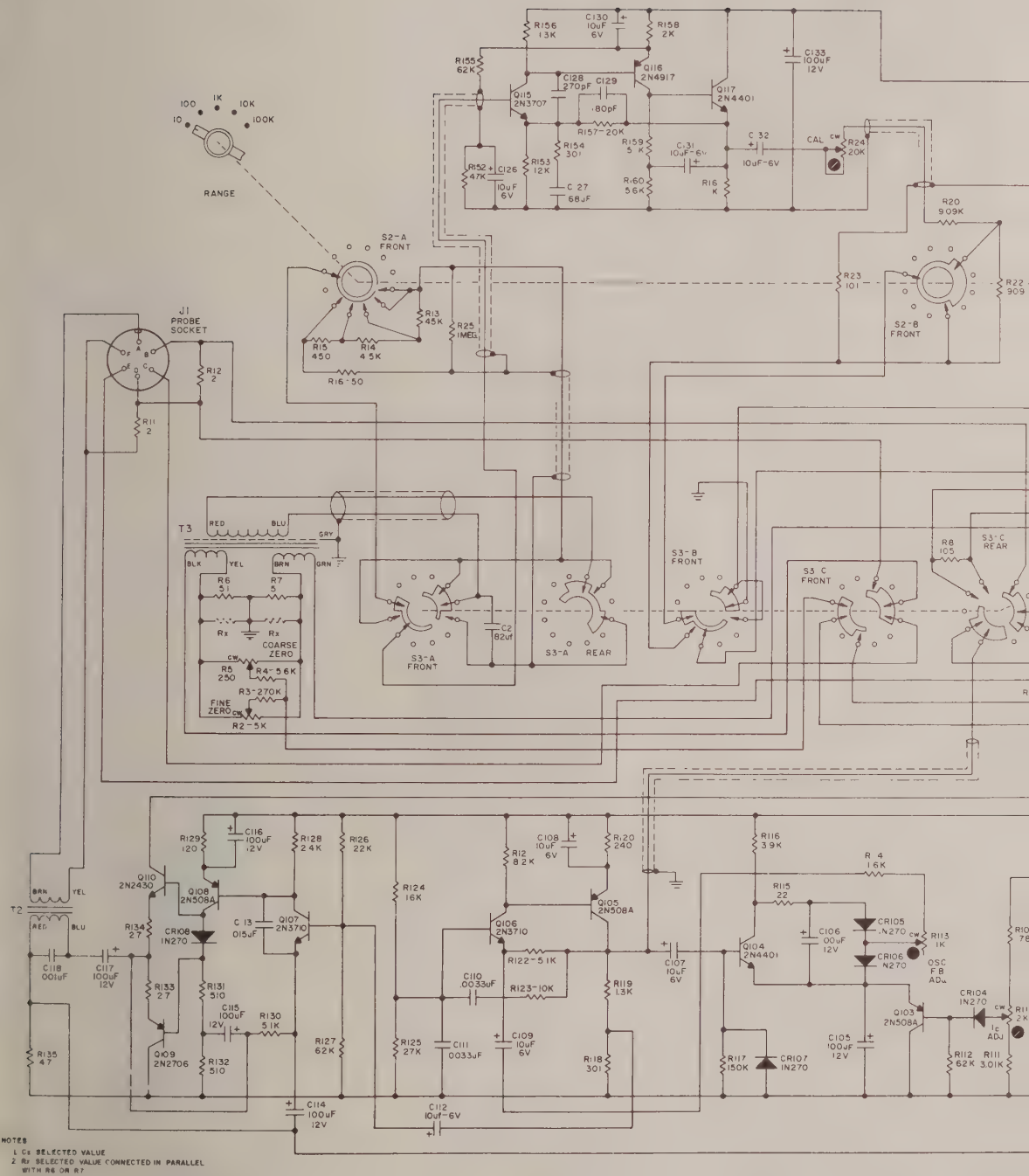
Schematic Ref.	Value	Spec.	Type	Bell Part No.
C116	100μF	12 V	EM	23160
C117	100μF	12 V	EM	23160
C118	0.001μF 1000 V	20%	Cer	25510
C119	10μF	6 V	EM	22930
C120	0.001μF 1000 V	20%	Cer	25510
C121	100μF	12 V	EM	23160
C122	100μF	12 V	EM	23160
C123	1μF 75 V	10%	MME	24300
C124	0.047μF 200 V	10%	MME	24530
C125	0.047μF 200 V	10%	MME	24530
C126	10μF	6 V	EM	22930
C127	0.68μF 75V	10%	MME	24180
C128	270pF 1000 V	20%	Cer	25470
C129	180 pF 1000 V	10%	Cer	25400
C130	10μF	6 V	EM	22930
C131	10μF	6 V	EM	22930
C132	10μF	6 V	EM	22930
C133	100μF	12 V	EM	23160
C134	10μF	6 V	EM	22930
C135	10μF	6 V	EM	22930
C136	1μF 75 V	10%	MME	24300
C137	270 pF 1000 V	20%	Cer	25470
C138	10μF	6 V	EM	22930
C139	10μF	6 V	EM	22930
C140	100μF	12 V	EM	23160
Q118	2N3707	Transistor		28990
Q119	PN4917	Transistor		29150
Q120	2N2430	Transistor		28910
Q121	2N2706	Transistor		28930
Q122	2N4124	Transistor		29070
	2N4126	Transistor		29080
Q123	2N4124	Transistor		29070
	2N4126	Transistor		29080
Q124	2N4124	Transistor		29070
	2N4126	Transistor		29080
CR1	1N4003	Diode		28090
CR2	1N4003	Diode		28090
CR101	1N270	Diode		27990
CR102	1N270	Diode		27990
CR103	1N5230	Zener Diode		28440
CR104	1N270	Diode		27990
CR105	1N270	Diode		27990
CR106	1N270	Diode		27990
CR107	1N270	Diode		27990
CR108	1N270	Diode		27990
CR109	1N279	Diode		27990
CR110	1N270	Diode		27990
CR111	1N270	Diode		27990
CR112	1N270	Diode		27990

NOTE: Connector that will mate with J6 the rear BCD output connector is Cinch #57-30240



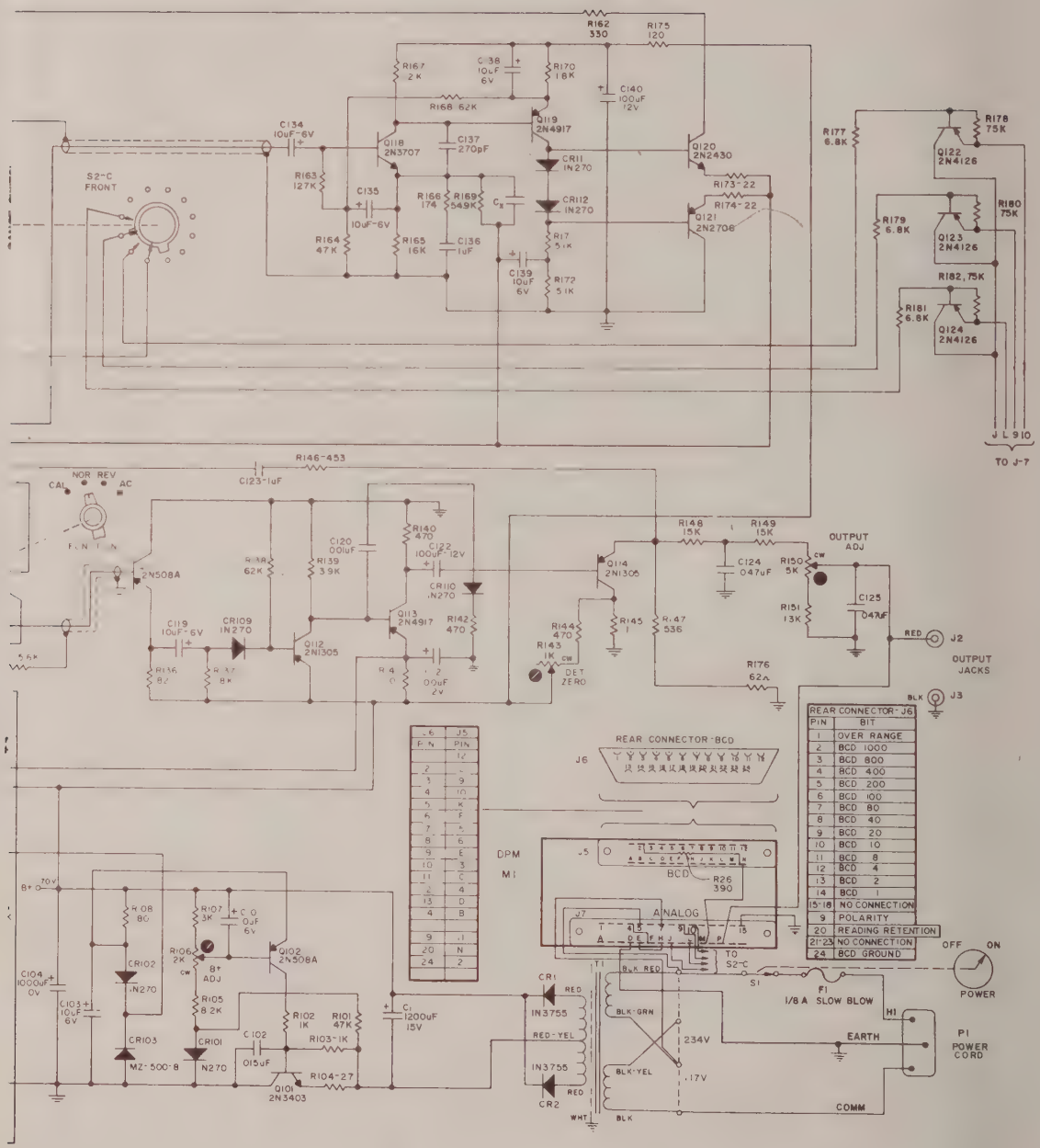
CIRCUIT BOARD LAYOUT
FIGURE VI-3


OUTPUT JACKS
LOW PASS FILTER
DIGITAL PANEL METER
BCD OUTPUT CONNECTOR
SYNCHRONOUS DEMODULATOR
SYNC SIGNAL
AMPLIFIER
RANGE SWITCH
CAL CONTROL
PREAMPLIFIER
AMPLITUDE REGULATED 5KHZ OSCILLATOR
CURRENT REGULATED AMPLIFIER
T3 INPUT TRANSFORMER
T2 CURRENT OUTPUT TRANSFORMER
COARSE ZERO
FINE ZERO
POWER SUPPLY REGULATOR
FUSE
HALL ELEMENT
HALL VOLTAGE
CONTROL CURRENT
CAL RESISTOR
PROBE
BLOCK DIAGRAM
MODEL 615



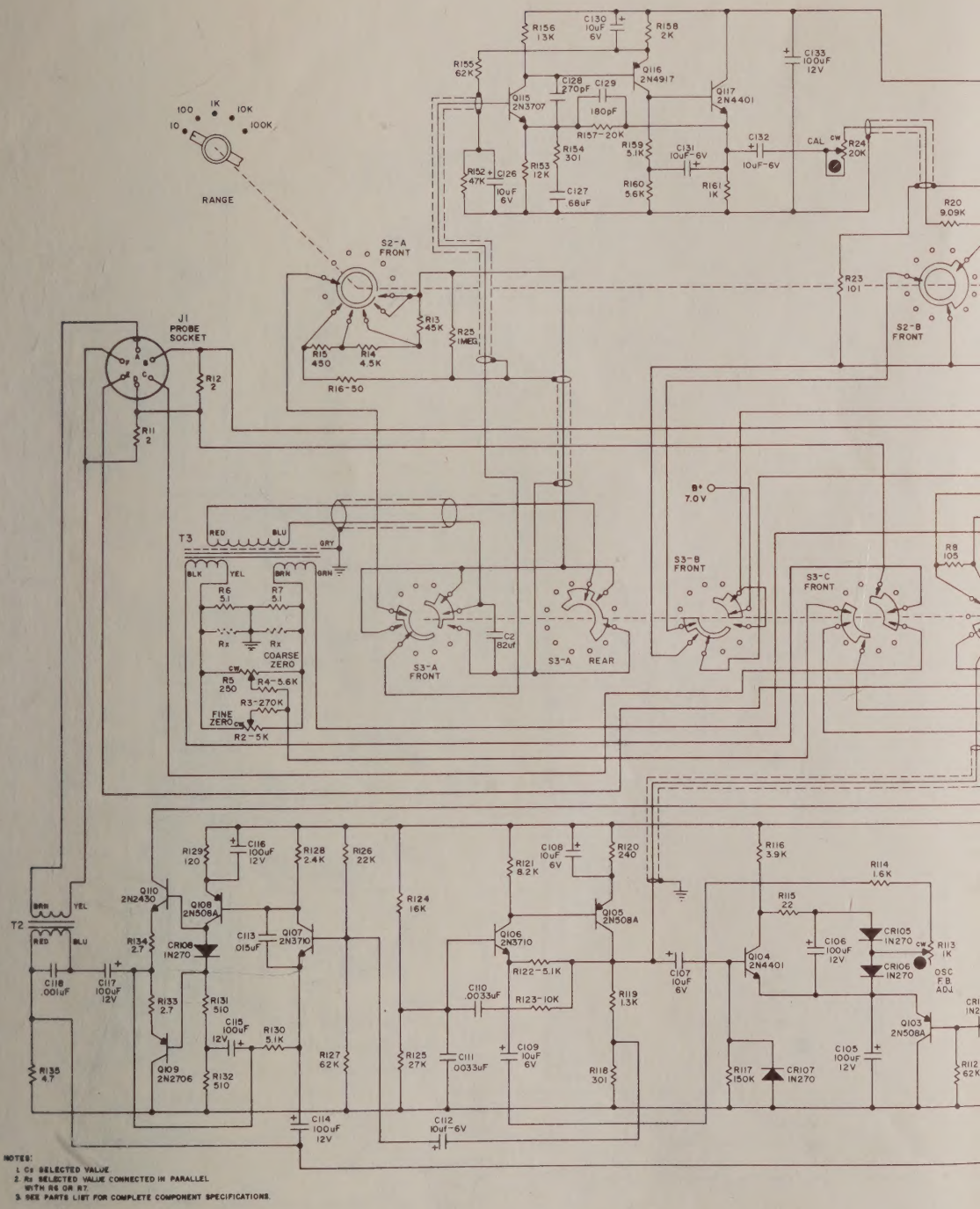
NOTES

1. Cx SELECTED VALUE
2. Rx SELECTED VALUE CONNECTED IN PARALLEL WITH R6 OR R7
3. SEE PARTS LIST FOR COMPLETE COMPONENT SPECIFICATIONS



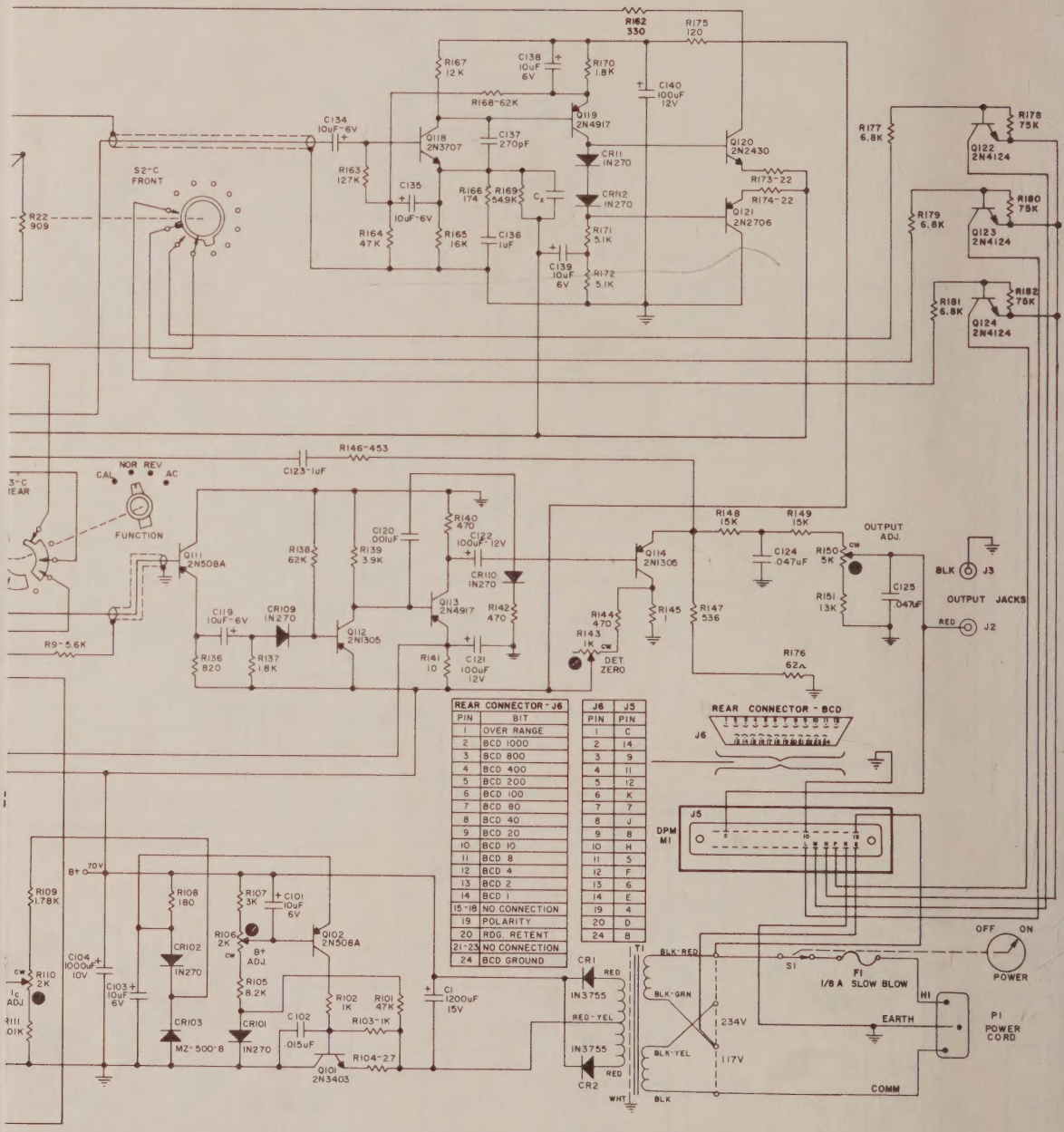
SCHEMATIC, MODEL 615 GAUSSMETER
SERIAL NO's 161455 AND BELOW

UD-3103



NOTES:

1. Cx SELECTED VALUE.
2. Rx SELECTED VALUE CONNECTED IN PARALLEL WITH R6 OR R7.
3. SEE PARTS LIST FOR COMPLETE COMPONENT SPECIFICATIONS.



REAR CONNECTOR - J6	
PIN	BIT
1	OVER RANGE
2	BCD 1000
3	BCD 800
4	BCD 400
5	BCD 200
6	BCD 100
7	BCD 80
8	BCD 40
9	BCD 20
10	BCD 10
11	BCD 8
12	BCD 4
13	BCD 2
14	BCD 1
15-18	NO CONNECTION
19	POLARITY
20	RDG. RETENT
21-23	NO CONNECTION
24	BCD GROUND

J6	J5
PIN	PIN
1	C
2	14
3	9
4	11
5	12
6	K
7	7
8	J
9	8
10	H
11	5
12	F
13	6
14	E
19	4
20	D
24	8

SCHEMATIC, MODEL 615 GAUSSMETER
SERIAL NO's 161456 AND ABOVE

UD-3919

WARRANTY

F.W. BELL, INC. warrants each instrument of its manufacture to be free from defects in material and workmanship. Our oblication under this warranty is limited to servicing or adjusting any instrument returned to our factory for that purpose, and to replacing any defective parts thereof (excluding electron tubes, batteries, transistors and probe sensing elements, which parts are covered by a standard EIA 90-day warranty). This warranty covers instruments which, within one year after delivery to the original purchaser, shall be returned with transportation charges prepaid by the original purchaser, and which upon examination shall disclose to our satisfaction to be defective. If it is determined that the defect has been caused by misuse or abnormal conditons of operation, repairs will be billed at cost after submitting an estimate to the purchaser.

F.W. BELL, INC. reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or libialities on the part of F.W. BELL, INC., and F.W. BELL, INC. neither assumes nor authorizes any other person to assume for them any other liability in connection with the sales of F.W. BELL, INC. instruments.

DAMAGE IN SHIPMENT

The instrument should be examined and tested as soon as it is received. If it does not operate properly, or is damaged in any way, immediately file a claim with the carrier. The claim agent will provide report forms. A copy of the completed form should be forwarded to us. We will then make the necessary arrangements for repair or replacement. All correspondence concerning this instrument should include model and serial numbers.

SHIPPING INSTRUCTIONS

Always use the original shipping carton and inserts, if possible, or pack the instrument in a sturdy container and surround the entire instrument with two or three inches of shock-absorbing material.

F.W. BELL

6120 Hanging Moss Road
Orlando, Florida 32807
Phone: 305-678-6900
TWX: 810-853-3115